

HyspIRI: Sampling and Time Series Issues

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May 18, 2011

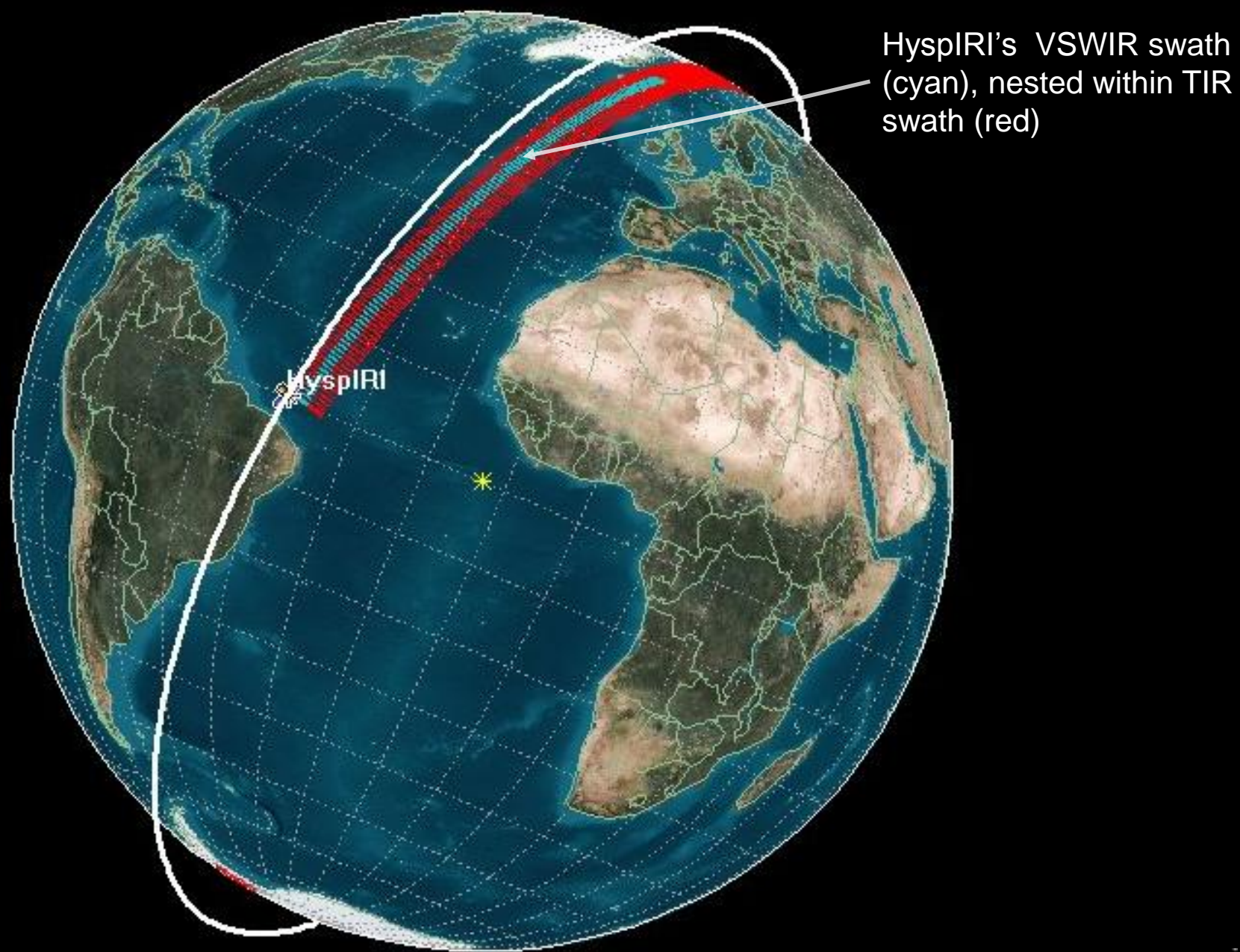
Introduction

Context

- VSWIR spectrometer observations:
“The longest revisit time acceptable is a month or so; . . .” (NRC, 2007, p. 204)
 - Trading off spatial resolution and temporal resolution, we arrived at a 60 m GSD (pixel spacing) and a swath width of ~150 km, suited to provide full global coverage in a polar, sun-synchronous, 19-day repeating orbit.
- “A multispectral imager similar to ASTER is required in the thermal data IR region. . . and a pixel size of less than 90 m.” (NRC, 2007, p. 115)
 - Trading off requirements for spatial and temporal resolution, we arrived at a ~60 m GSD and swath width of ~600 km; suited to provide full global coverage in a sun-synchronous, 5-day near-repeating orbit.

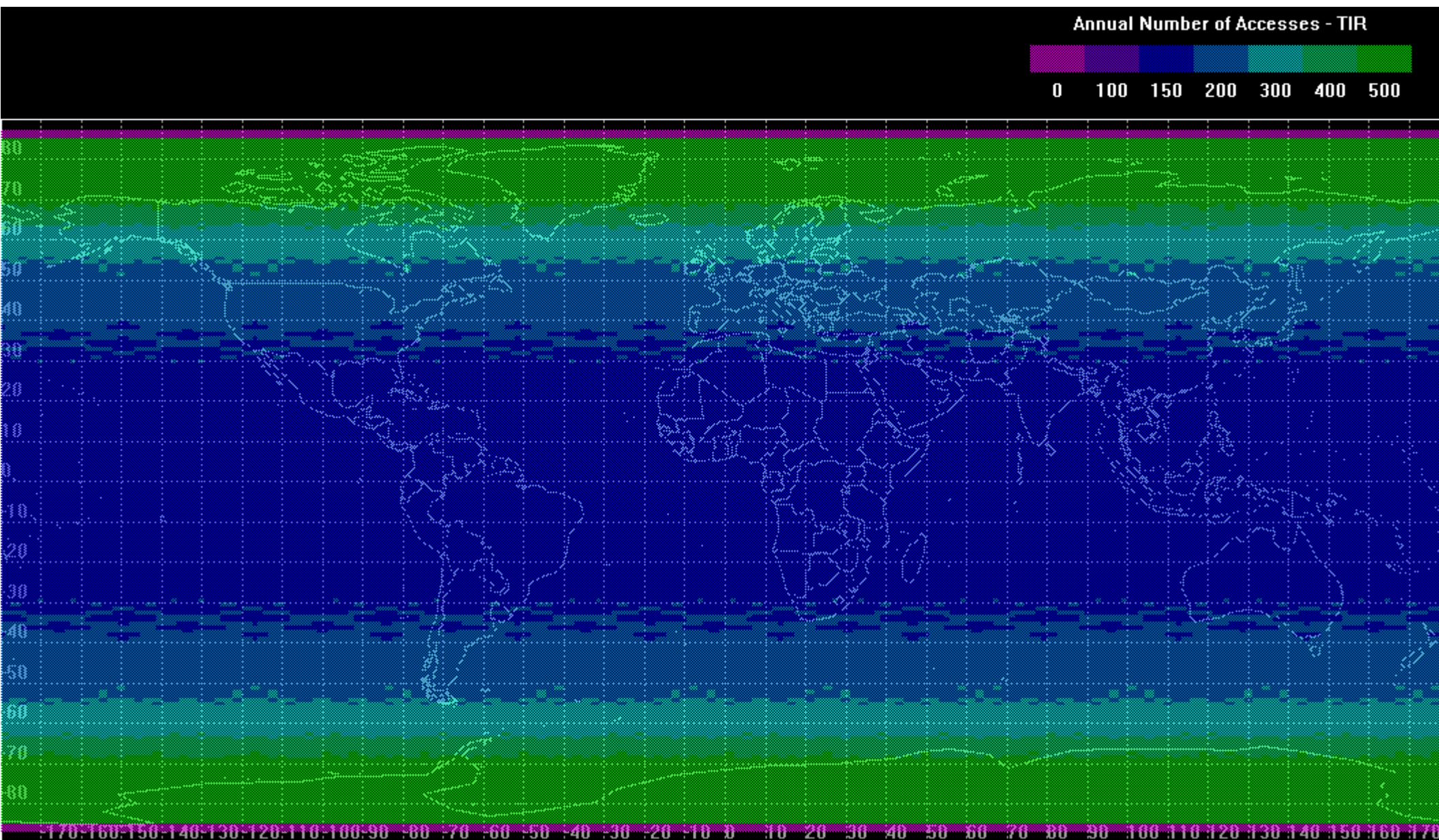
Outline

- TIR imaging opportunities
 - Variation in frequency with latitude
 - Overpass times/dates for example sites
- VSWIR imaging opportunities
 - Seasonal coverage
 - Variation in overpass time with latitude
- Cross-track sampling geometry
- Generality of findings:
 - HypsIRI reference orbit vs. other daylight sun-synchronous orbits? vs. other Earth referenced orbits?



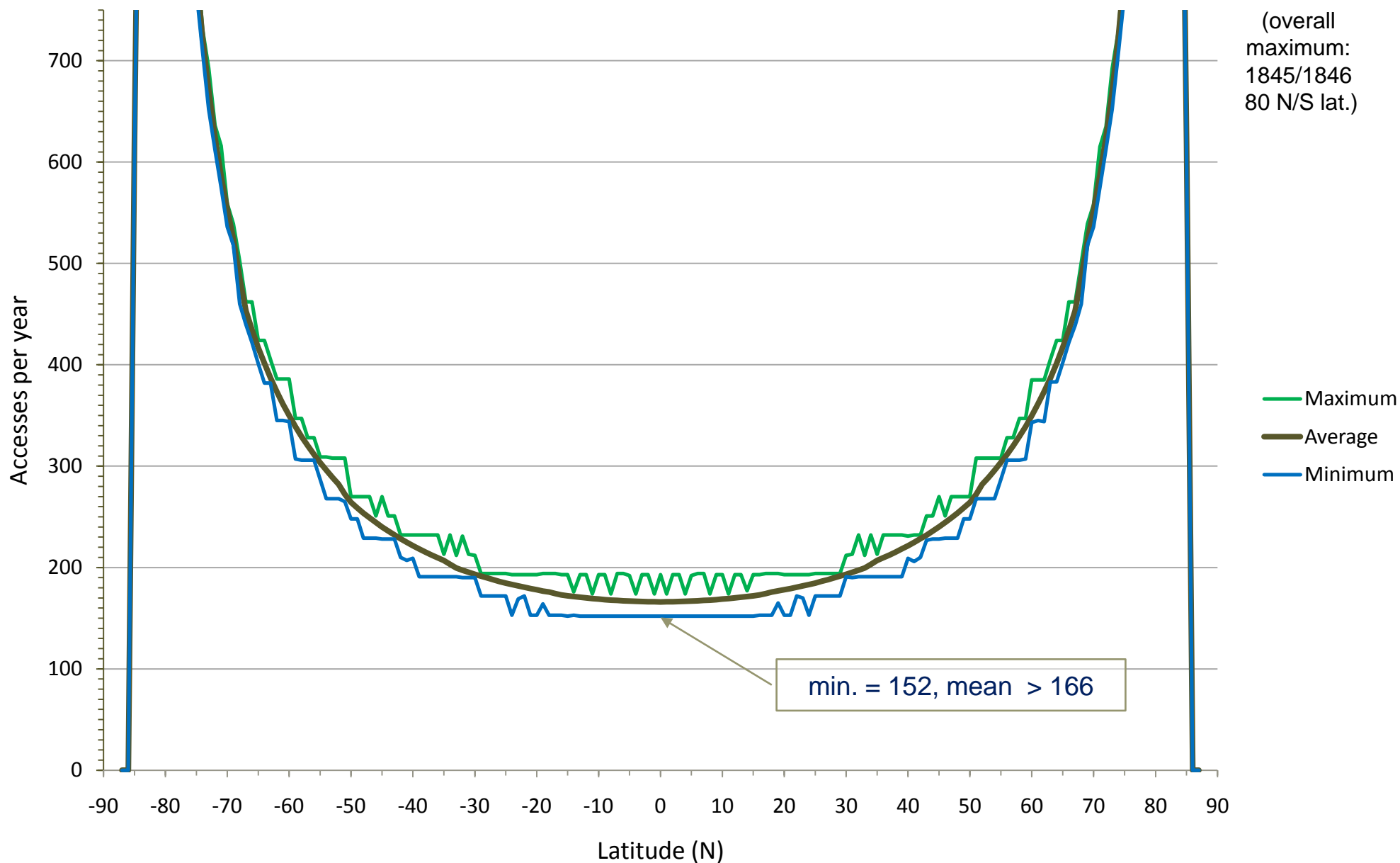
Equinox (20 March)

Annual TIR imaging opportunities in a 5-day near-repeating orbit, 1 yr. simulation

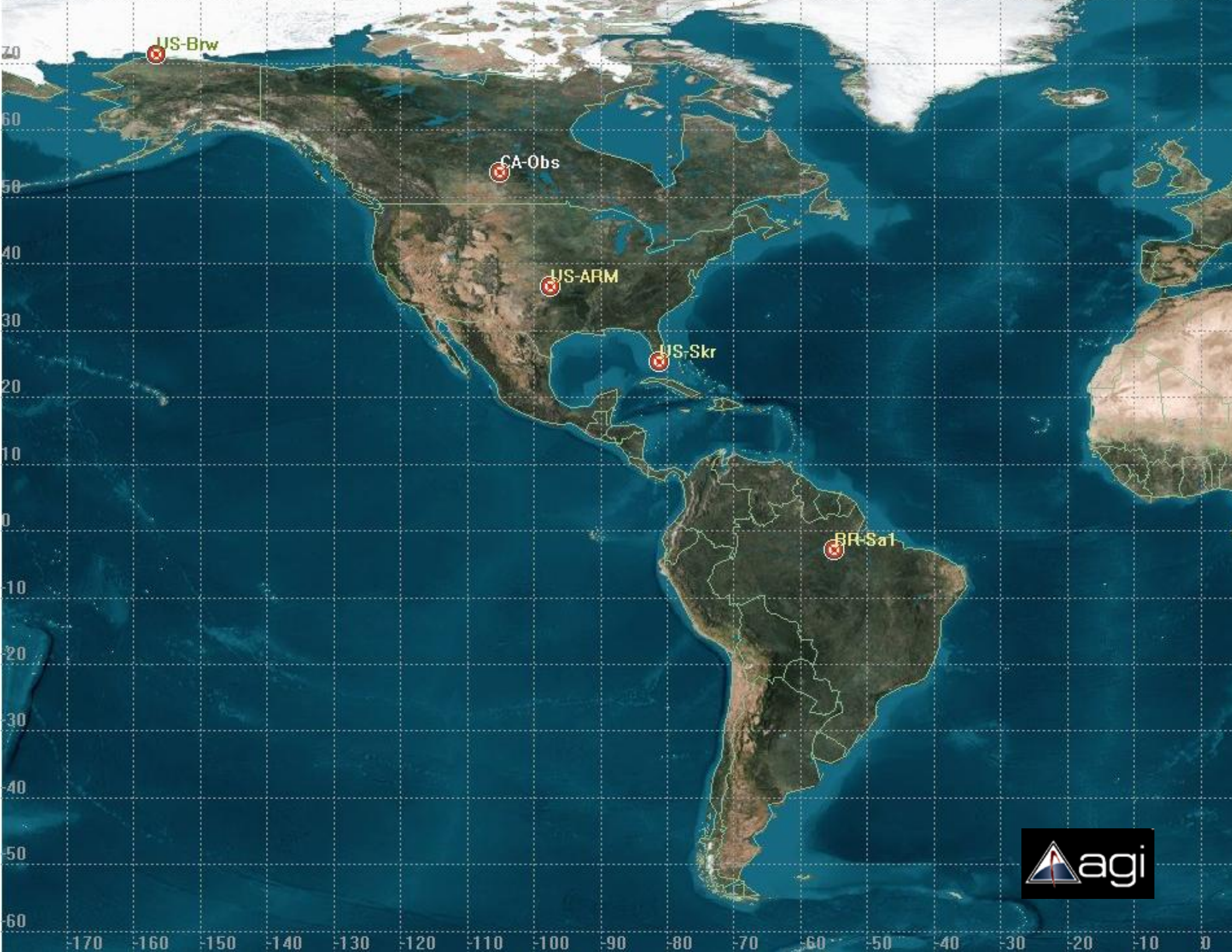


Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: $\pm 25.46^\circ$ (60 m pixel GSD at nadir, 9272 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010. Plotted May 3, 2010.

Annual TIR imaging opportunities in a 19/5-day repeat HyspIRI reference orbit
Swath: 50.92°, symmetric about nadir. Sampled using a 1 by 1 deg. coverage.

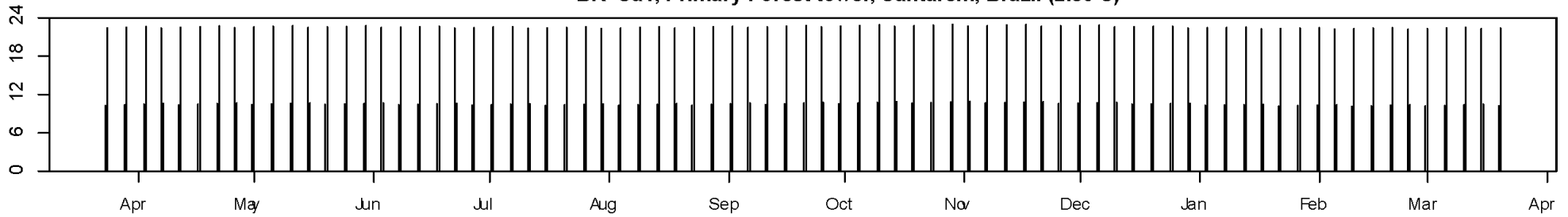


Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: $\pm 25.46^\circ$ (60 m pixel GSD at nadir, 9272 cross-track pixels).
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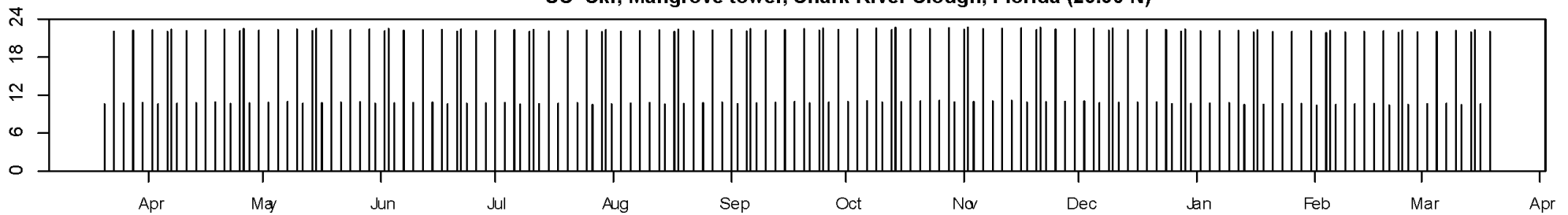


TIR accesses for 1 simulated year

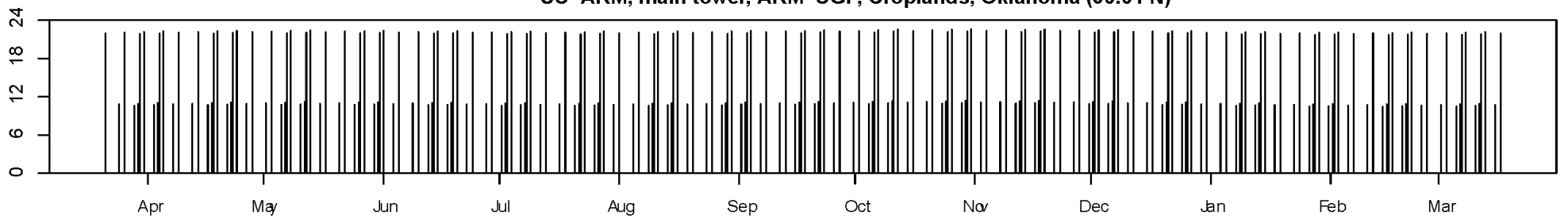
BR-Sa1, Primary Forest tower, Santarem, Brazil (2.86 S)



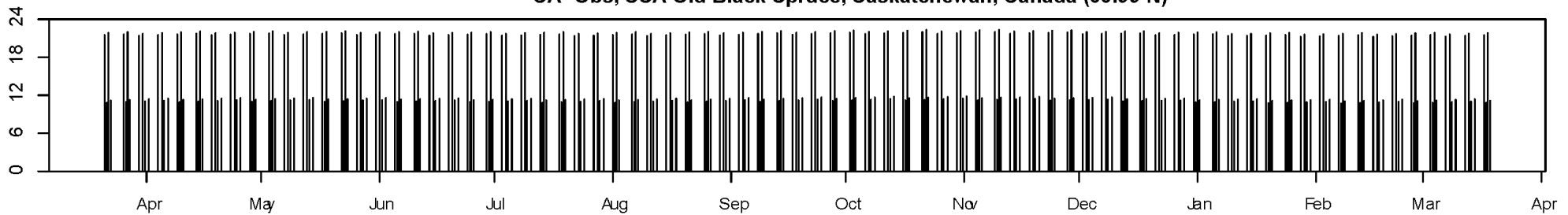
US-Skr, Mangrove tower, Shark River Slough, Florida (25.36 N)



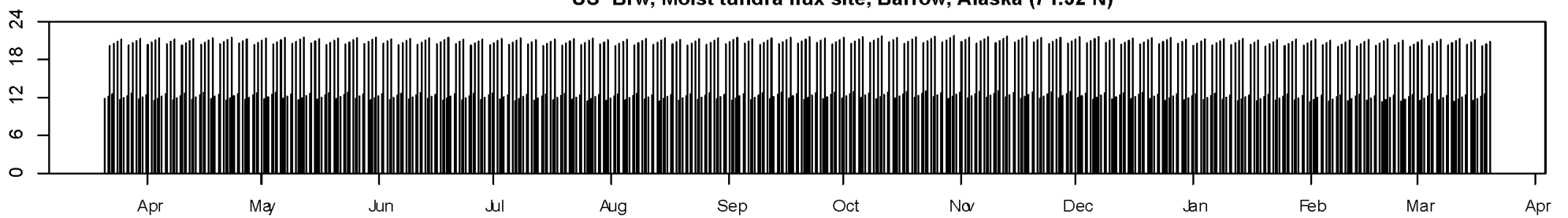
US-ARM, main tower, ARM-SGP, Croplands, Oklahoma (36.61 N)



CA-Obs, SSA Old Black Spruce, Saskatchewan, Canada (53.99 N)



US-Brw, Moist tundra flux site, Barrow, Alaska (71.32 N)

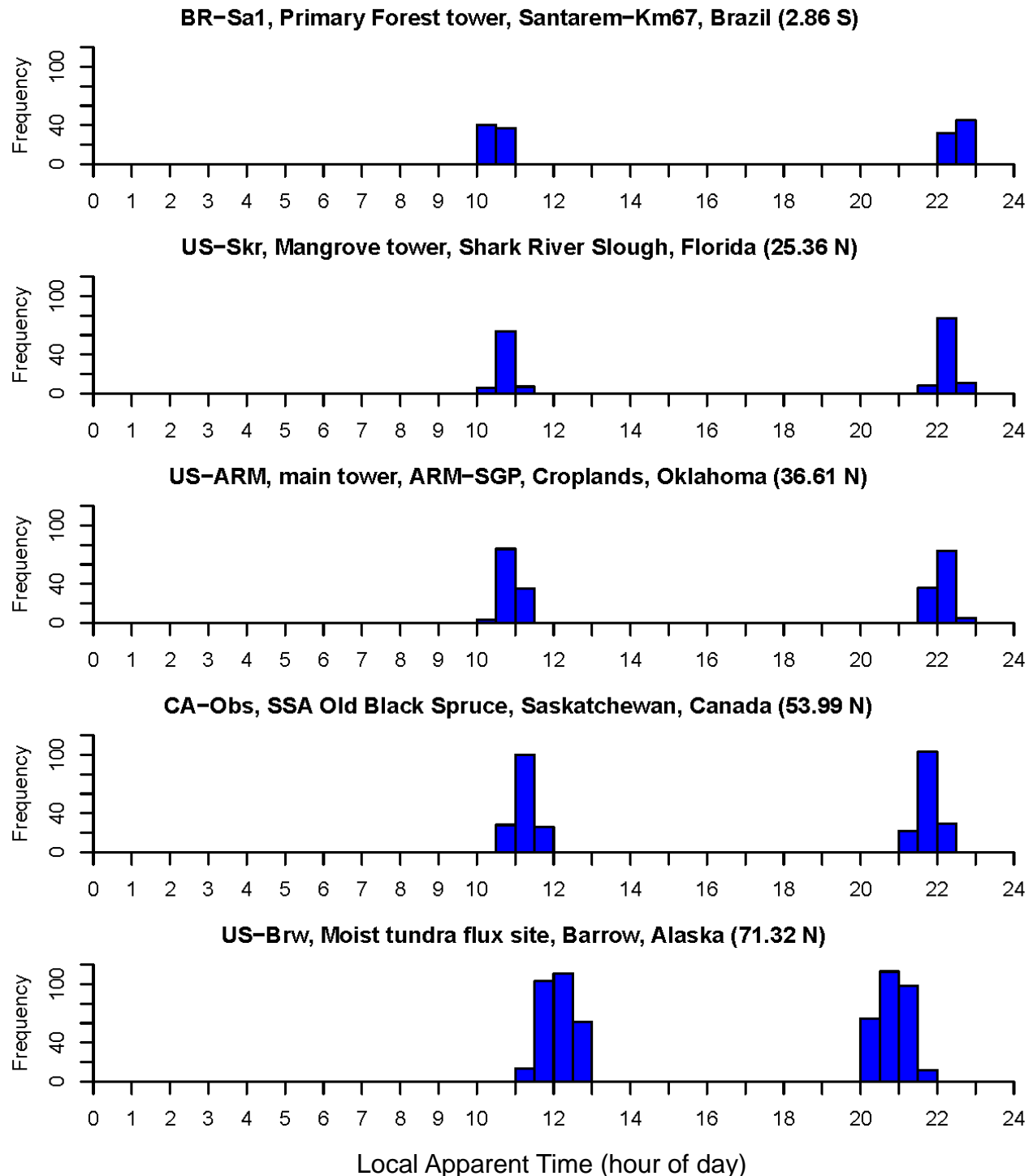


Local time of TIR overpasses of 5 FLUXNET sites, simulated for 1 year

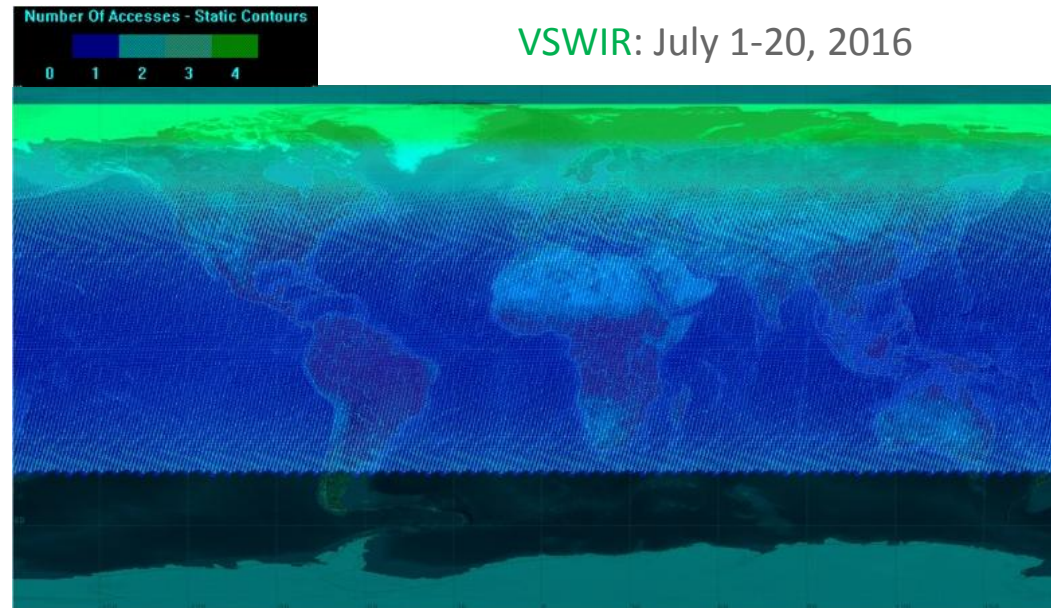
Near the equator, overpass times are separated by 12 hours, on average.

As the N latitude of the site increases, potential TIR collects are more frequent and less tightly clustered in local time.

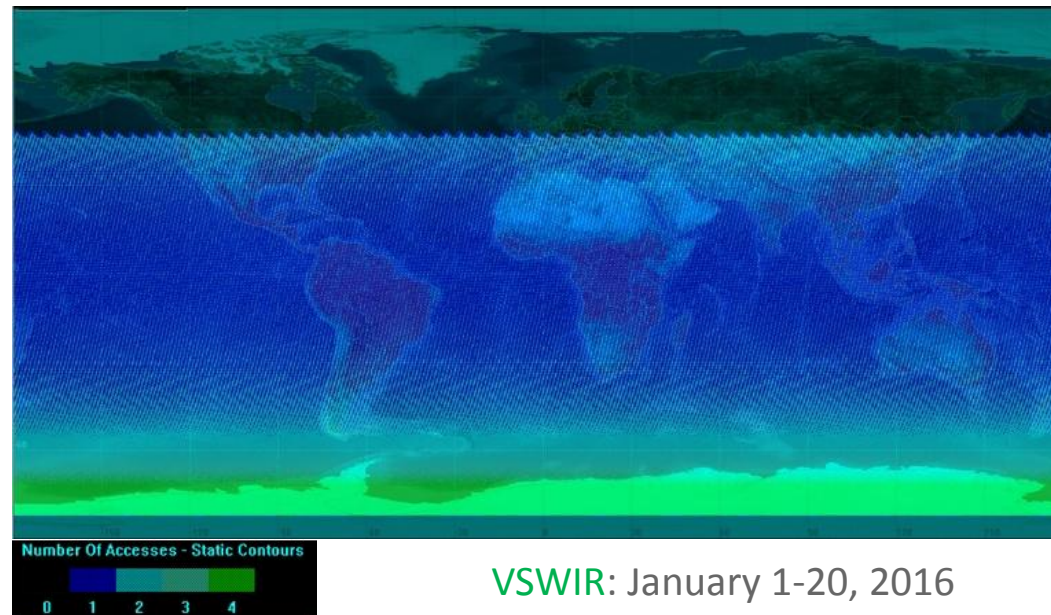
Also, moving toward the north orbit pole (82.1 N) daytime collects are later and night collects earlier, whereas moving south the reverse is true (not shown).



VSWIR coverage frequency varies seasonally

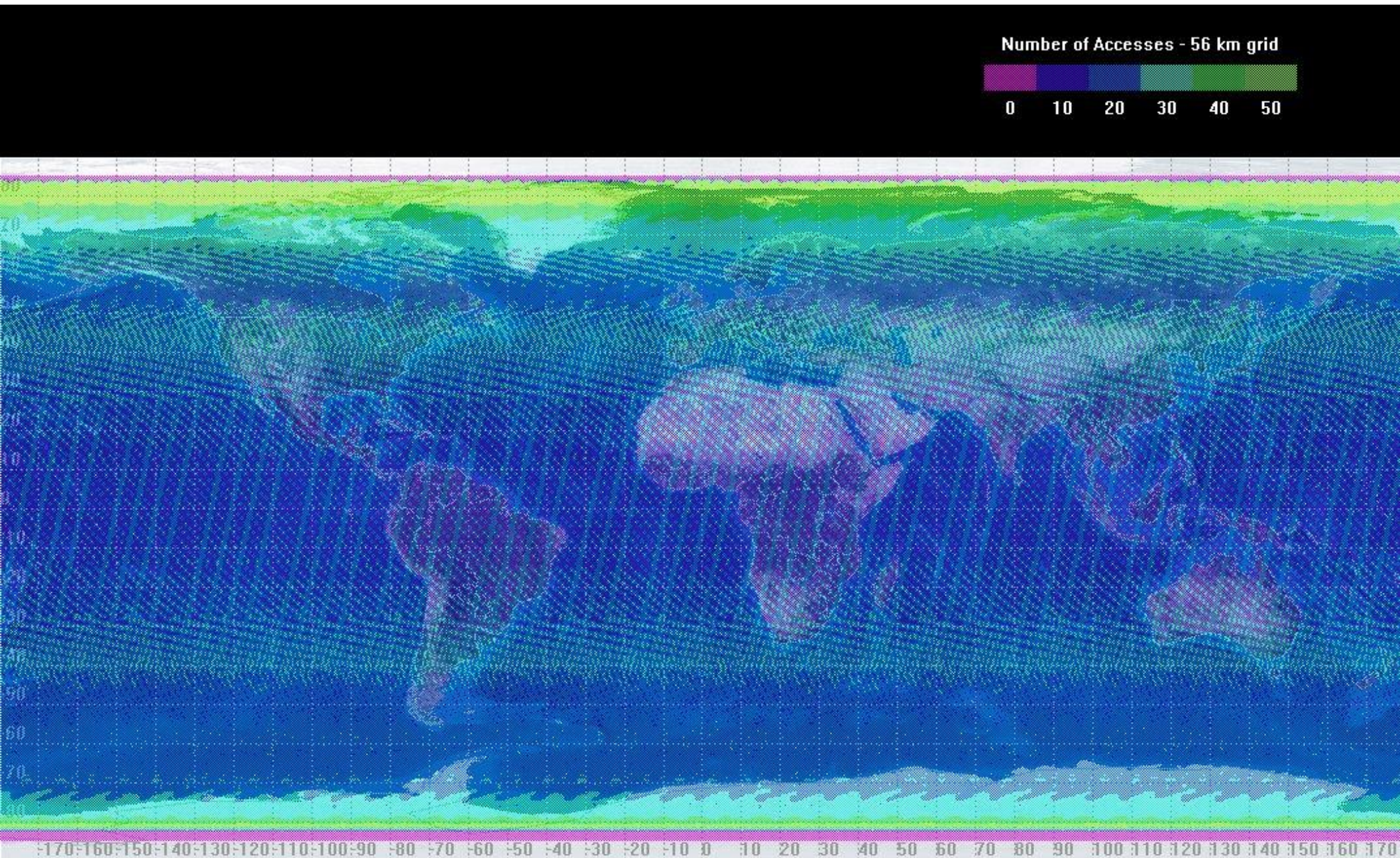


VSWIR coverage is limited by constraint: minimum 20 deg. Sun elevation angle.

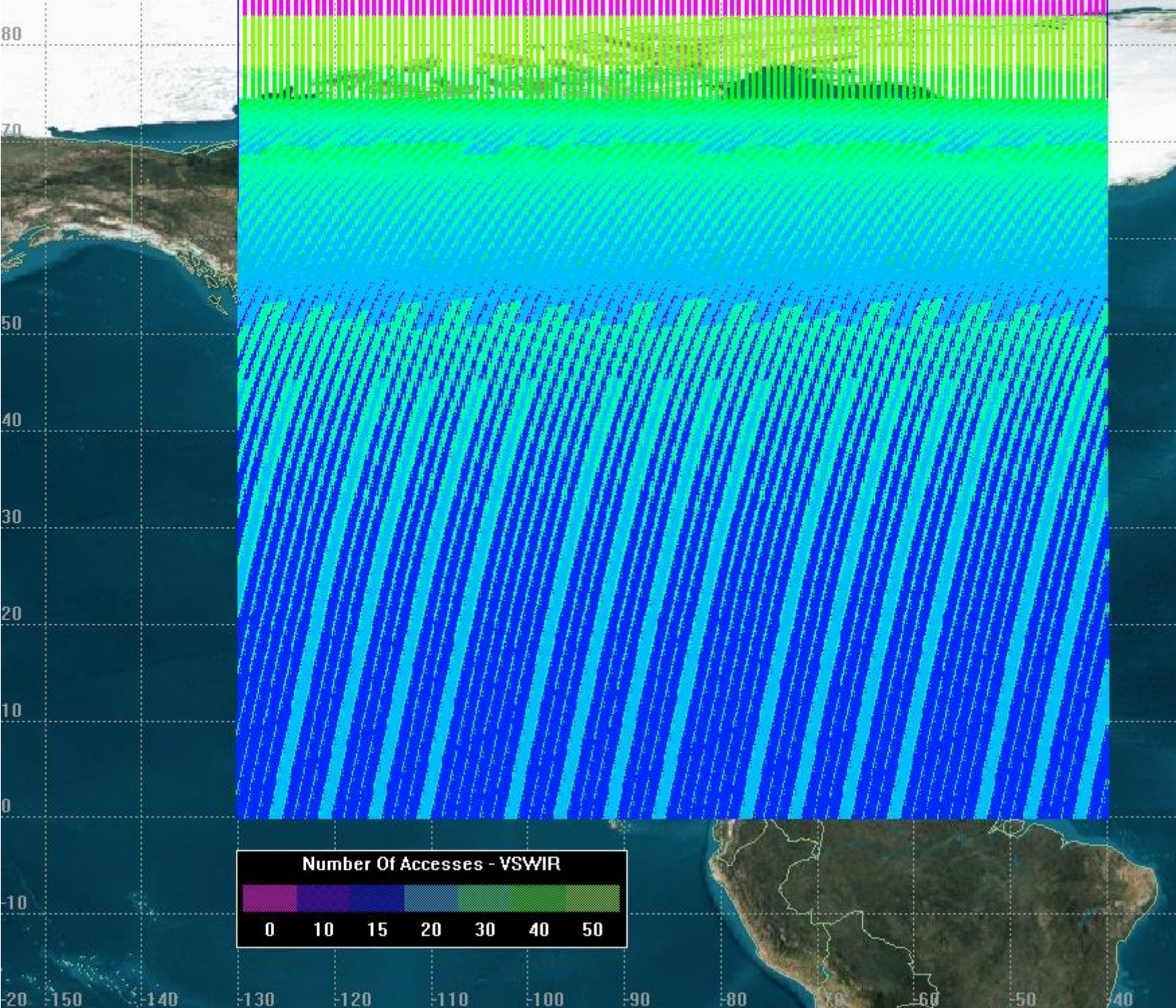


**Determined by
the minimum
solar elevation
angle and the
equatorial
crossing time.**

Annual VSWIR imaging opportunities in a 19-day repeating orbit, 1 yr. simulation, with a minimum solar elevation of 20°



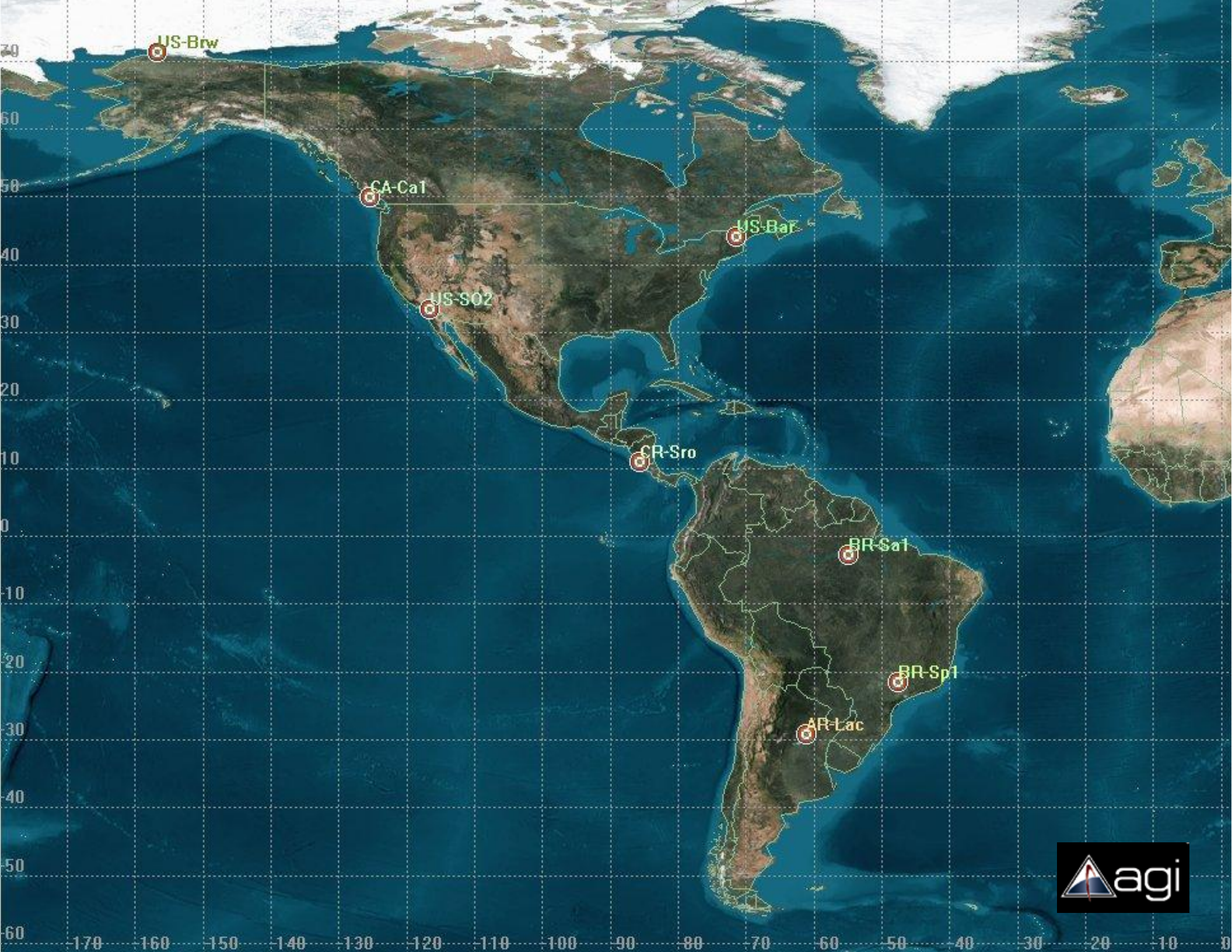
Nominal orbit: av. alt. 626.8 km, incl. 97.8° . VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2, August 20, 2010. Note aliasing with sample grid.



High resolution (1/8 degree) simulation of annual VSWIR coverage, 90 x 90 degree (lat, lon) region

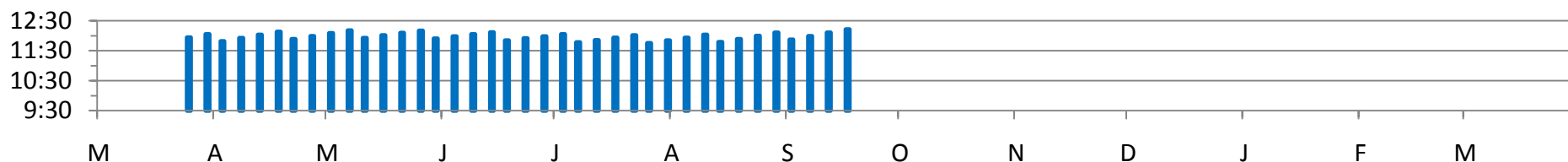
Strict repeating ground track vs. letting orbit drift, while controlling the crossing time?

Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels). R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2, August 17, 2010. Note aliasing at high latitudes.

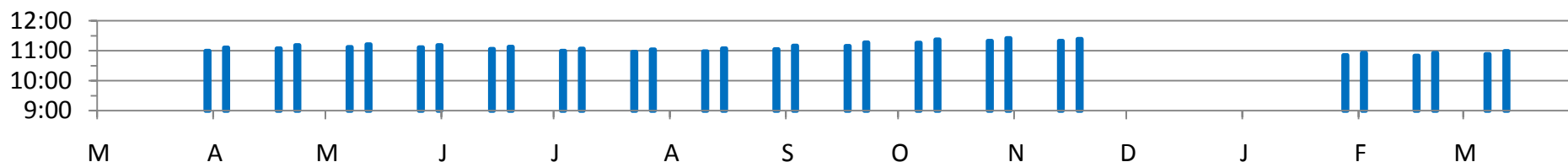


VSWIR accesses (SZA < 70°) for 1 simulated year

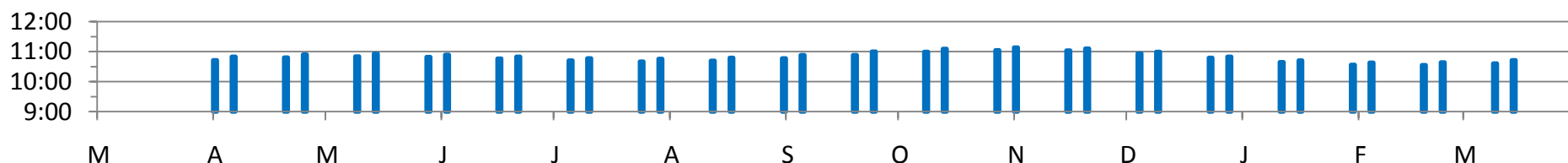
US-Brw: Moist Tundra, Barrow, Alaska (71.32 N)



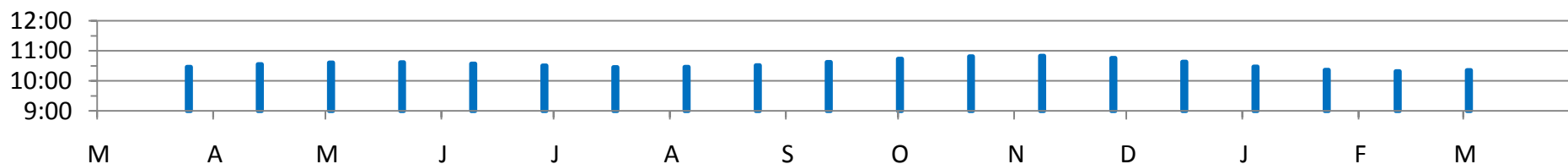
CA-Ca1: Campbell River, Maturing Douglas-fir, British Columbia, Canada (49.87 N)



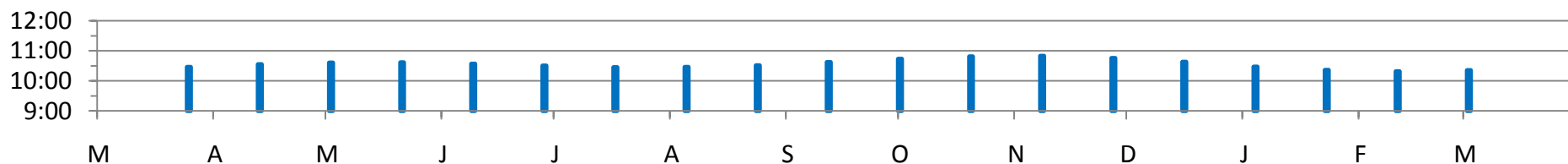
US-SO2: Sky Oaks Old Stand, Chaparral regrowing from 2003 fire, California (33.37 N)



CR-Sro: Santa Rosa, Mosaic of pasture & secondary forest, Costa Rica (10.81 N)

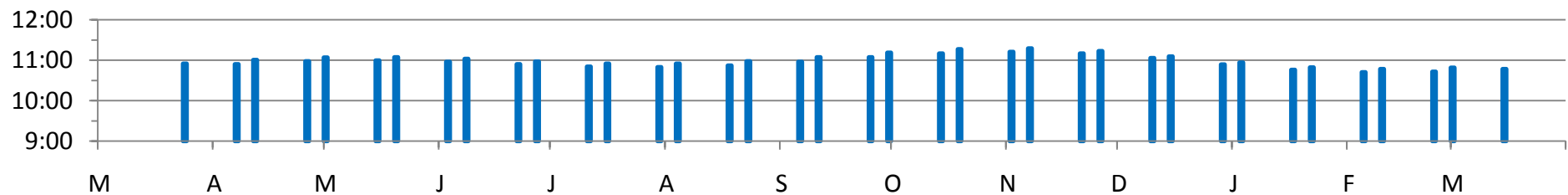


BR-Sa1: Santarem km 67 (LBA), Primary forest, Brazil (2.86 S)

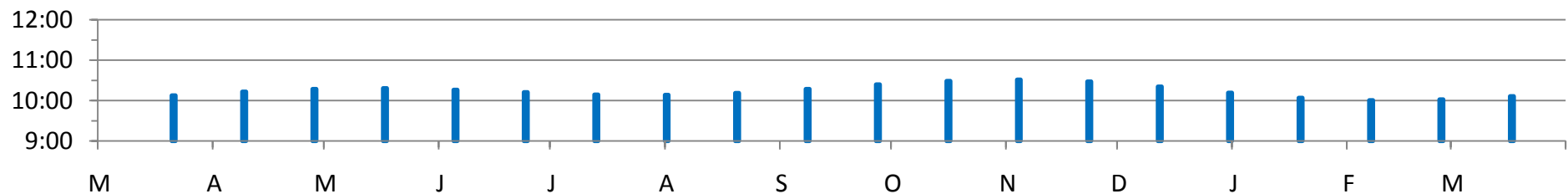


VSWIR accesses for 1 simulated year

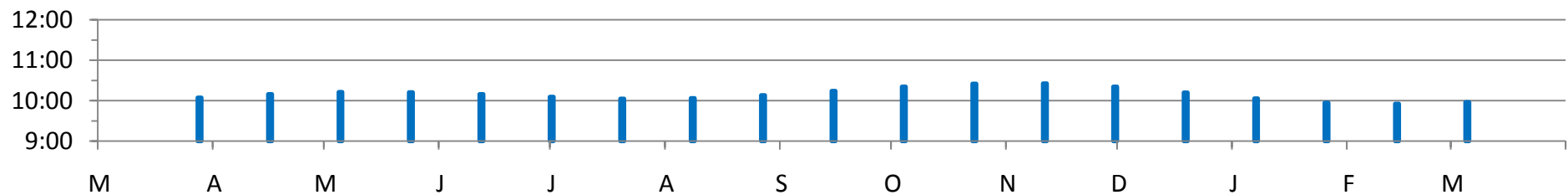
US-Bar: Bartlett Experimental Forest, Deciduous broadleaf, New Hampshire (44.06 N)



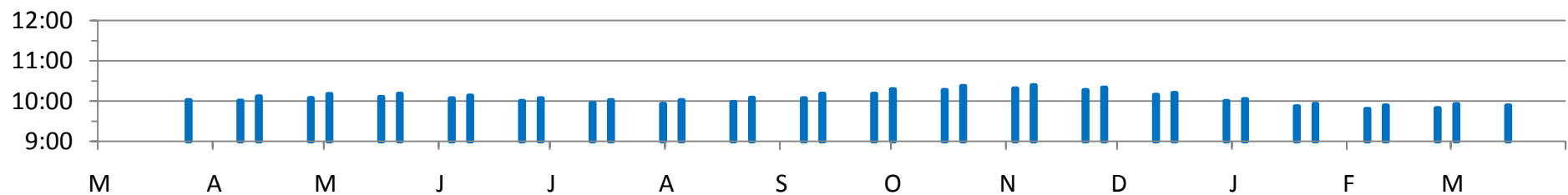
BR-Sp1: Sao Paulo Cerrado, Savannah vegetation, Brazil (21.62 S)



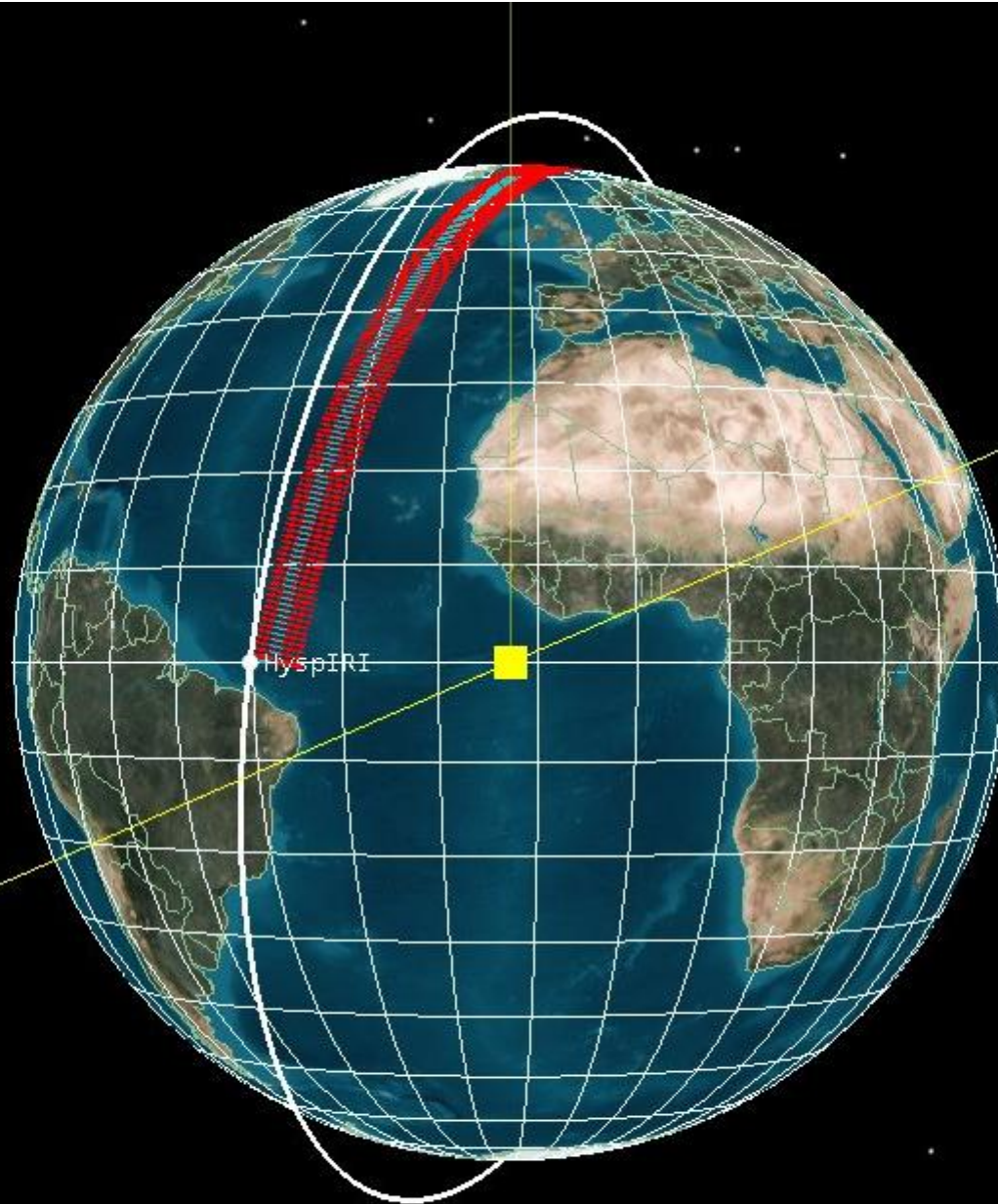
AR-Lac: La Ciguena Santa Fe, Croplands, Argentina (29.26 S)



AU-Tum: Tumbarumba, Wet temperate sclerophyll forest, Australia (35.66 S)

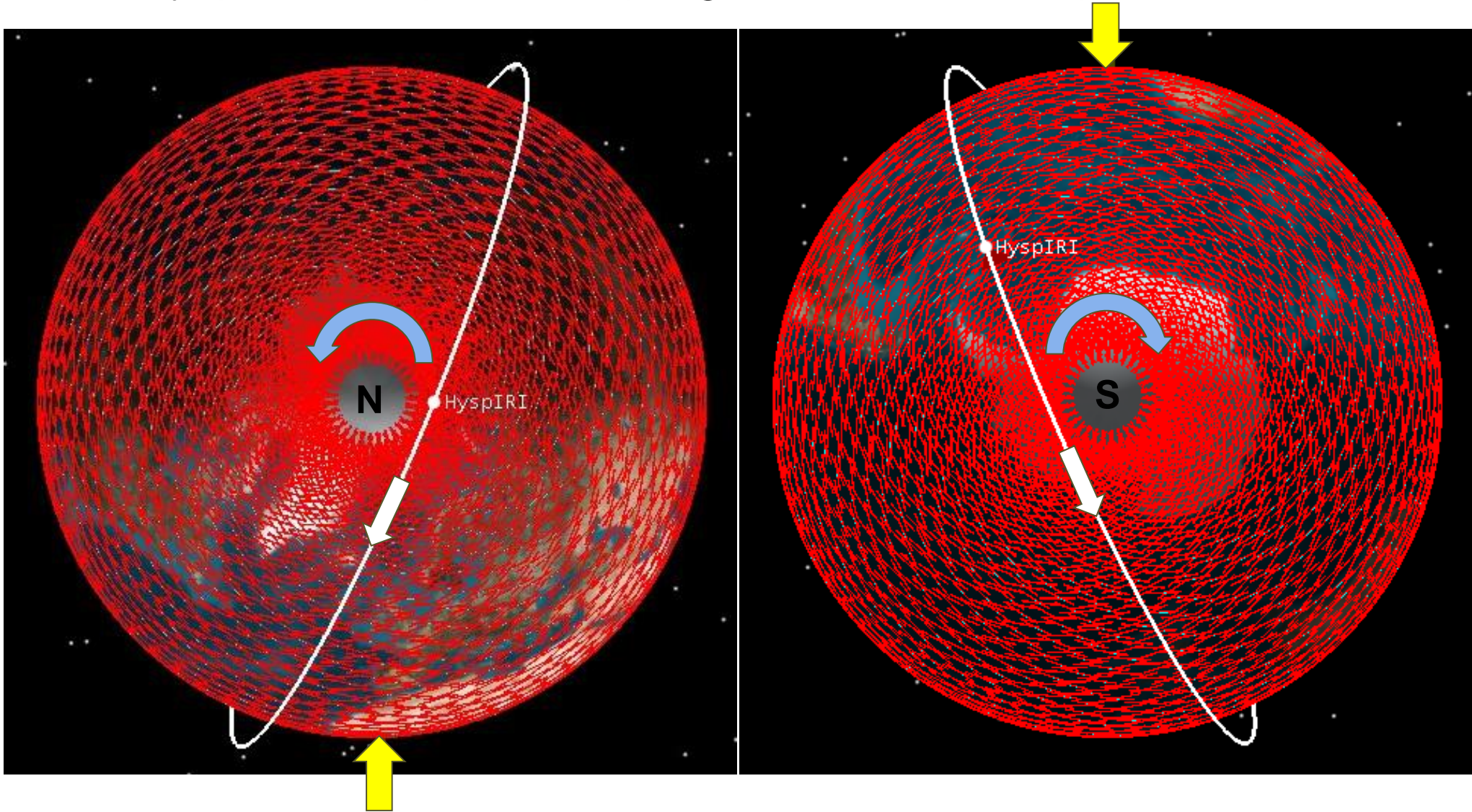


Daylight side of a sun-synchronous reference orbit, with 10:30 AM equatorial crossing (mean local time) at a descending orbit node. The sub-solar point (yellow) shows the location on Earth where the Sun is directly overhead, east of the ground track. Green line shows the plane of the ecliptic. 3-D view shown in Earth Inertial Axes.



20 March 12:59 UTC

HyspIRI near-polar sampling and illumination (late March)



HyspIRI's nominal mid-morning (10:30 AM) crossing time is on a descending orbit (N-to-S) pass. Hence the observatory passes over sunlit terrain while descending east of the North Pole and while approaching west of the South Pole. TIR coverage is similar at both poles. (Ground tracks of sun-synch. orbits cannot pass directly over the poles.) Key: yellow arrows--Sun vector; white arrows--orbital motion; blue arrows--Earth rotation. TIR sensor swath (red) marked at 60 second intervals.

R.G. Knox simulation with STK v9.2. Orbit: alt. 626.8 km, inclination: 97.8°. Simulated mission days March 20-25, 2009.
Earth graphics courtesy of Analytical Graphics Inc.

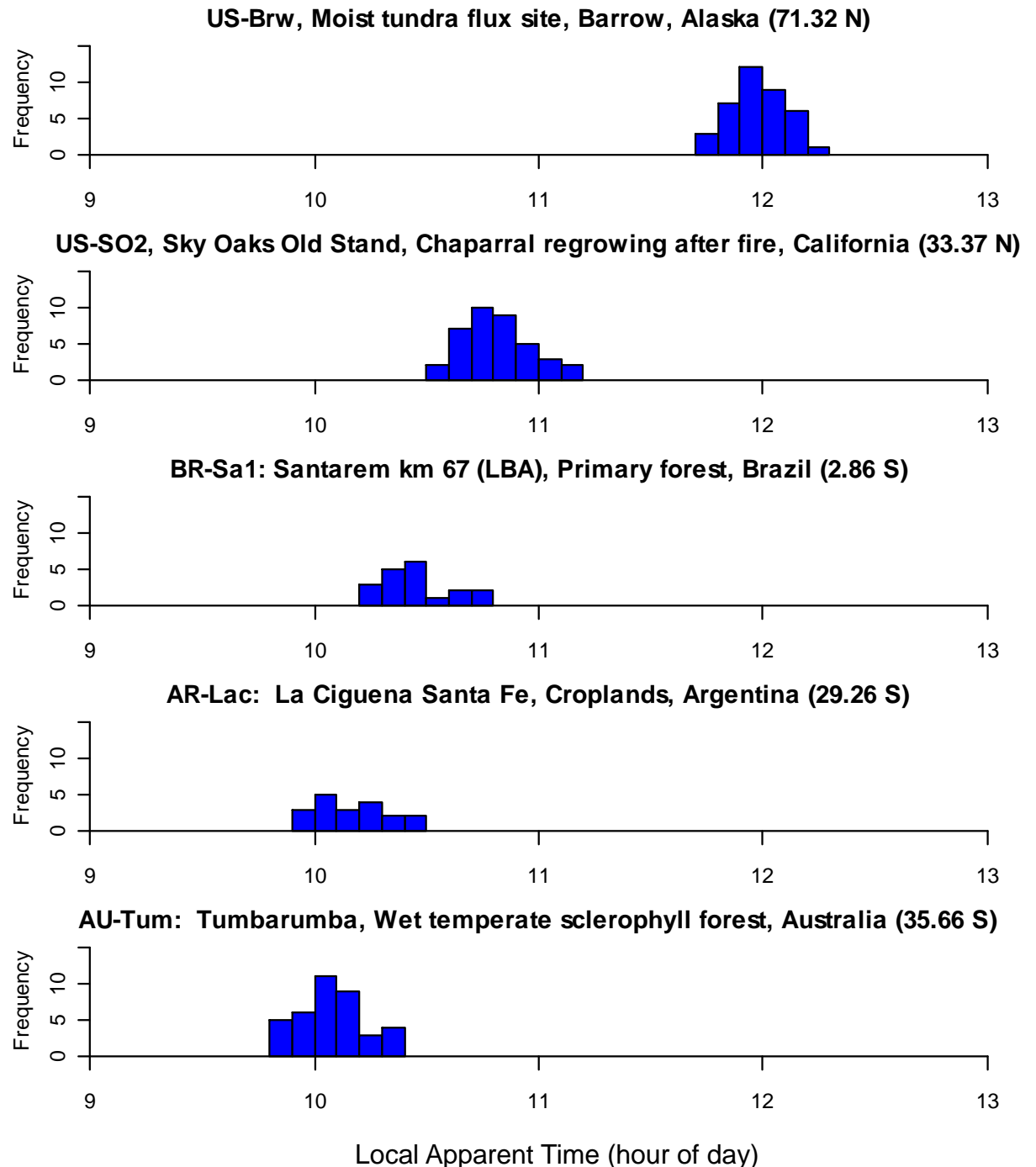
Local time of VSWIR overpasses of 5 FLUXNET sites, simulated for 1 year

Local apparent time, for a fixed mean local time, varies with the Earth's orbit. (Blue bars are 6 minutes wide.)

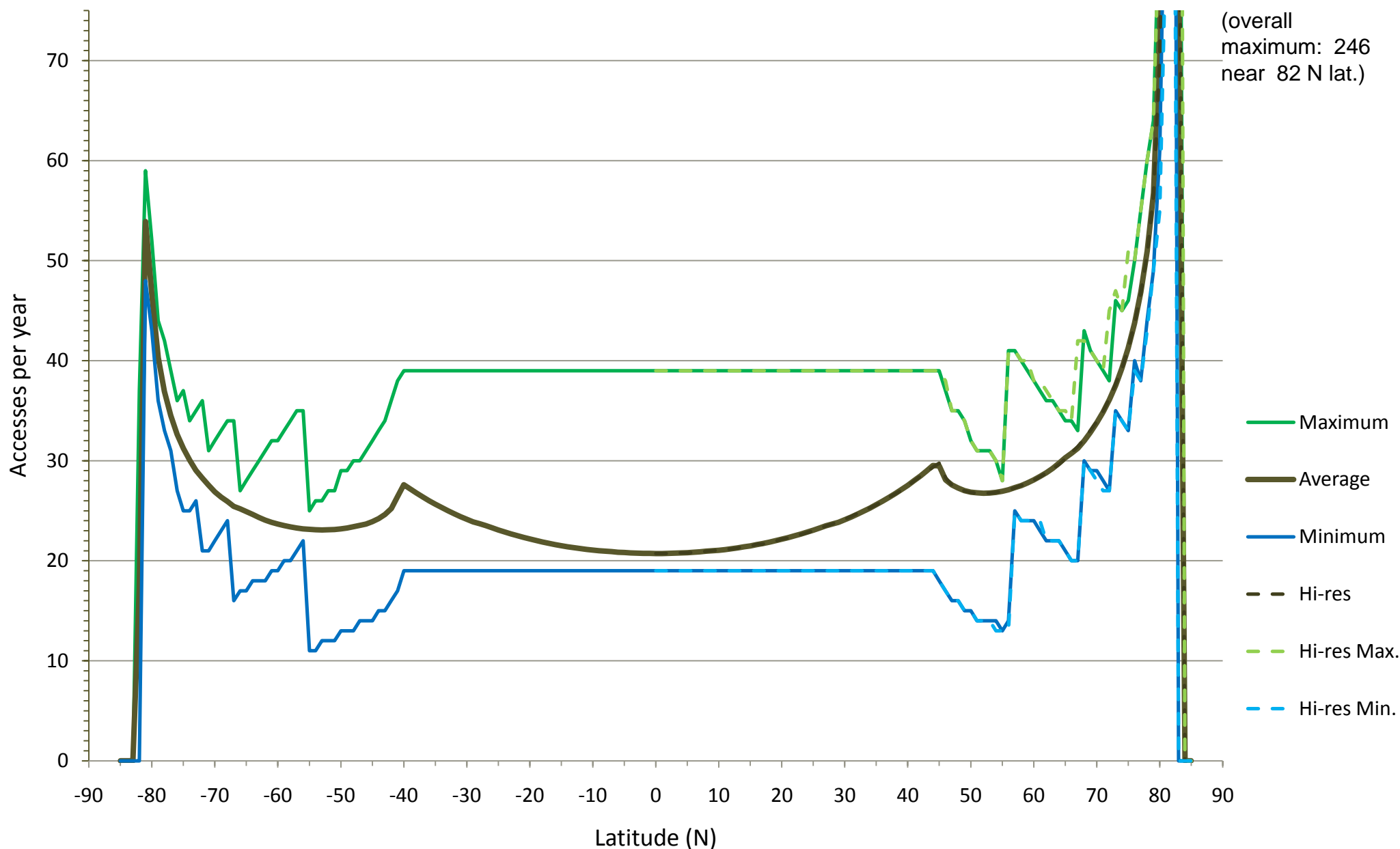
As the N latitude of the site increases, the local apparent times of potential VSWIR accesses also increase.

Near the north orbit pole (82.1 N) the local time of potential accesses may be nearly 6 hours later than when crossing the equator (not shown).

Moving toward the south orbit pole local times are progressively earlier in the morning.

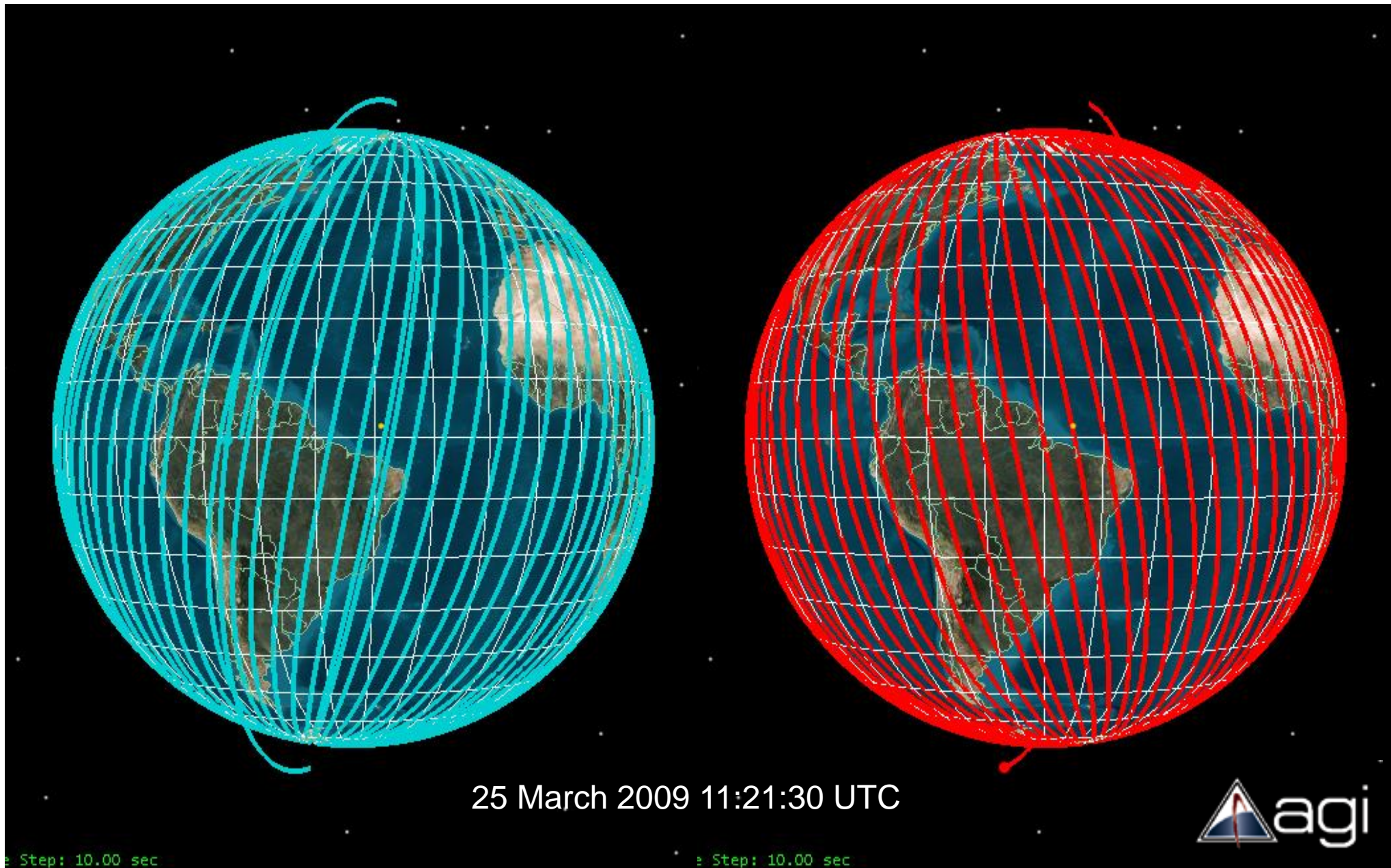


Annual VSWIR Imaging Opportunities by Latitude in a 19-day repeat HypsIRI Reference Orbit
 Swath: 13.62°, pointed 4° off-nadir; Local solar elevation angles > 20°; 56 km sample spacing
 (Hi-res sampling was a 90-by-90 degree region, sampled at 1/8 degree.)



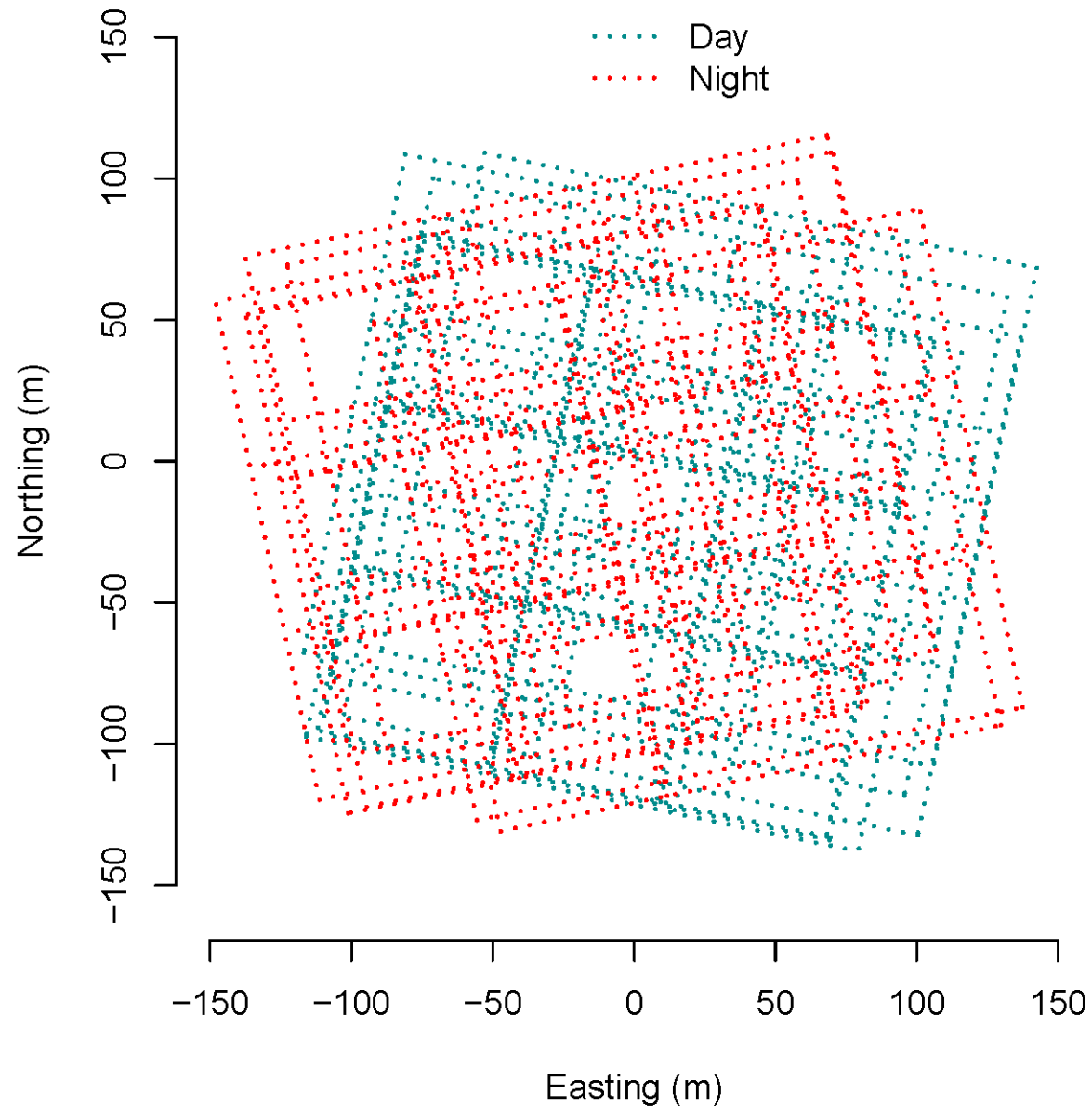
Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels).
 R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v9.2, Aug. 20, 2010.; hi-res subset Aug. 17.

HysplRI ground tracks shortly after completing a 5-day near repeat pattern:
(a) blue – descending (day) passes and orbit track;
(b) red – ascending (night) passes and orbit track.



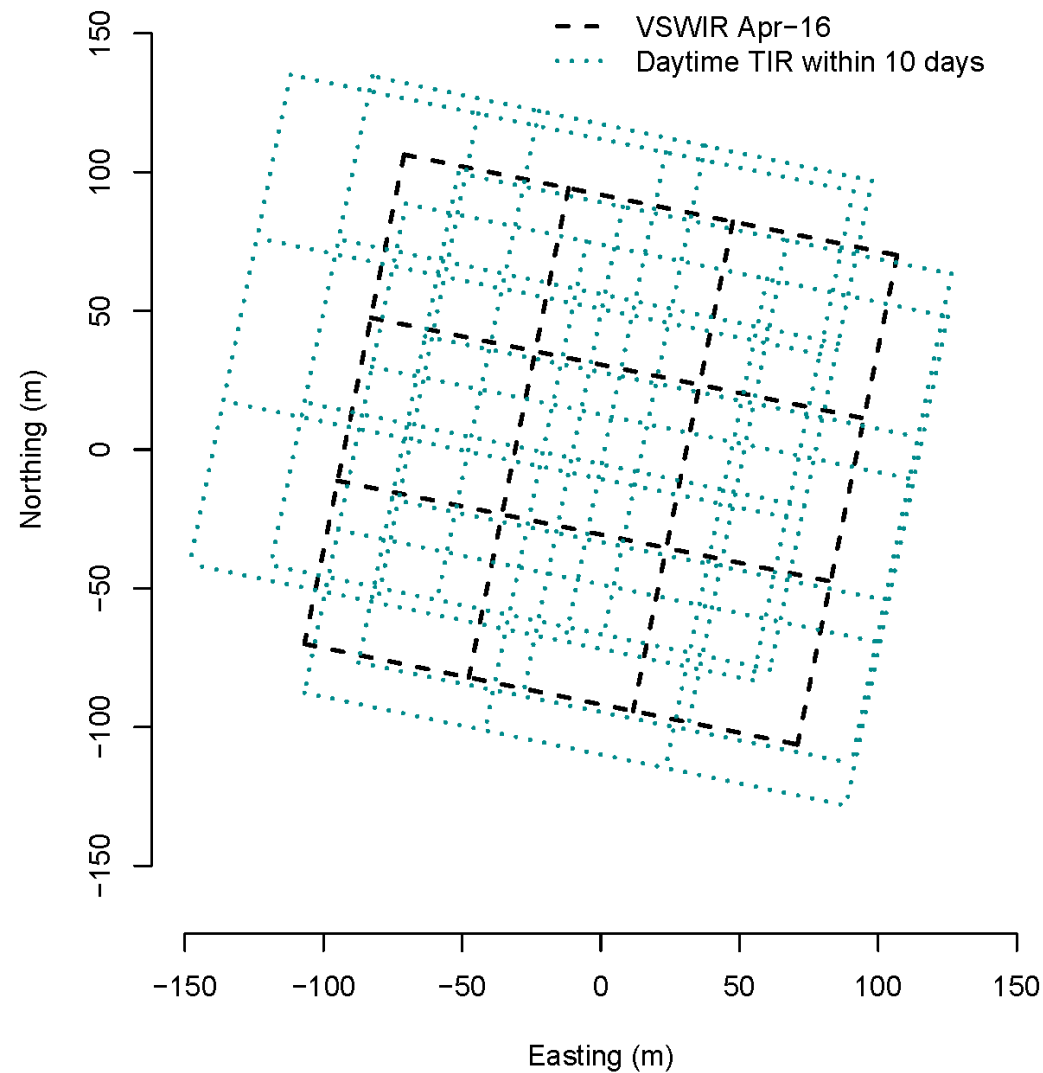
14 potential image collects for 1 simulated month (equatorial site)

1 Month of TIR Accesses to BR-Sa1, 3X3 pixels (GSD)

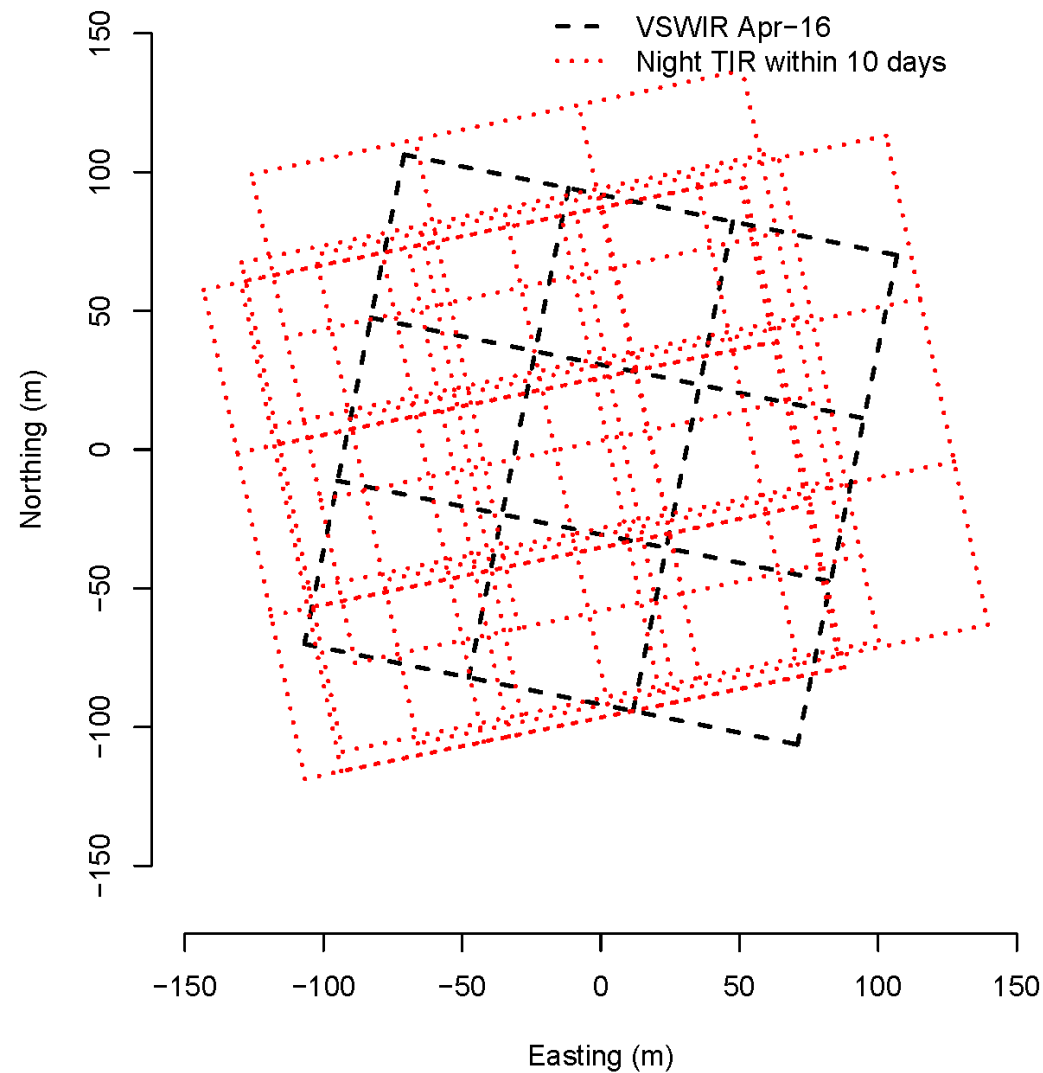


Example of potential HypsIRI TIR data within 10 days of VSWIR coverage, for a near-equatorial study site in Brazil

3X3 pixels (GSD) for BR-Sa1 VSWIR Accesses



3X3 pixels (GSD) for BR-Sa1 VSWIR Accesses



Daylight accesses (cyan) include 1 coincident with the SWIR coverage and 3 other dates.
Potential night data (red) include 5 overpasses, 1 within 13 hours of the SWIR coverage.

How general are these findings?

- Simon Hook asked (August 26, 2010):

“Which of these findings are specific to the particular orbit chosen for HyspIRI [reference orbit]? And which are true of broader classes of candidate orbits?”

- The HyspIRI reference orbit:
 - Circular low Earth orbit (LEO),
 - Repeating ground-track (19 days, with 5-day near repeat),
 - Combination of orbit average altitude (626.8 km) and inclination (97.8°) was chosen to be **sun-synchronous**, with a **nominal** equatorial crossing time of **10:30 AM** on the **descending node**.

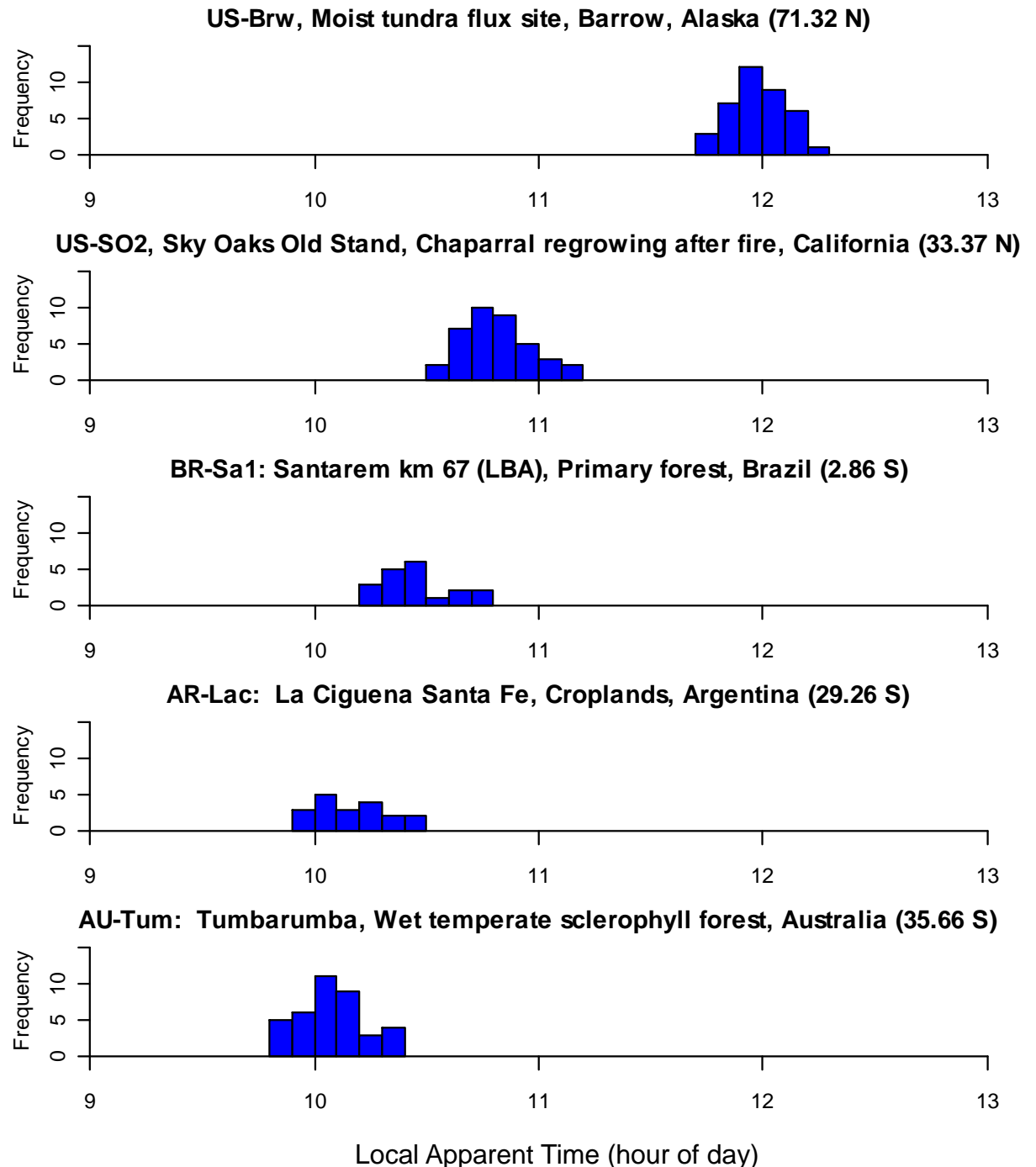
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Near the north orbit pole (82.1 N) the local time of potential accesses may be nearly 6 hours later than when crossing the equator (not shown).

Moving toward the south orbit pole, local times are progressively earlier in the morning.



Earth-referenced Satellite Orbits

- *Geosynchronous*: Orbit period = Earth's period of rotation (approx. 23 hr. 56 min.). Occurs with circular orbit average altitude of 35,786 km.

Special variant: *Geostationary (GEO)* orbit is an equatorial geosynchronous orbit that maintains a nearly fixed position over the equator. Common examples: GOES weather satellites, most commercial communication satellites, NASA tier II mission GEO-CAPE.

- *Low Earth Orbit (LEO)*: Orbit altitude remains below ~1000 km (below the inner Van Allen radiation belt)

Special variant: *Repeating ground track*, where subsatellite trace repeats.

- *Direct (prograde) Orbit*: Orbit moves eastward, with the Earth's rotation. Rotation of the launch site supplies up to ~464.5 m/s (*cf.* 11.18 km/s escape velocity at 0 km altitude)

Examples: most human spaceflight, International Space Station, low-cost experimental missions, GEO.

- *Polar Orbit*: Ground track passes near (*i.e.*, within 10 degrees latitude) Earth's N and S poles.

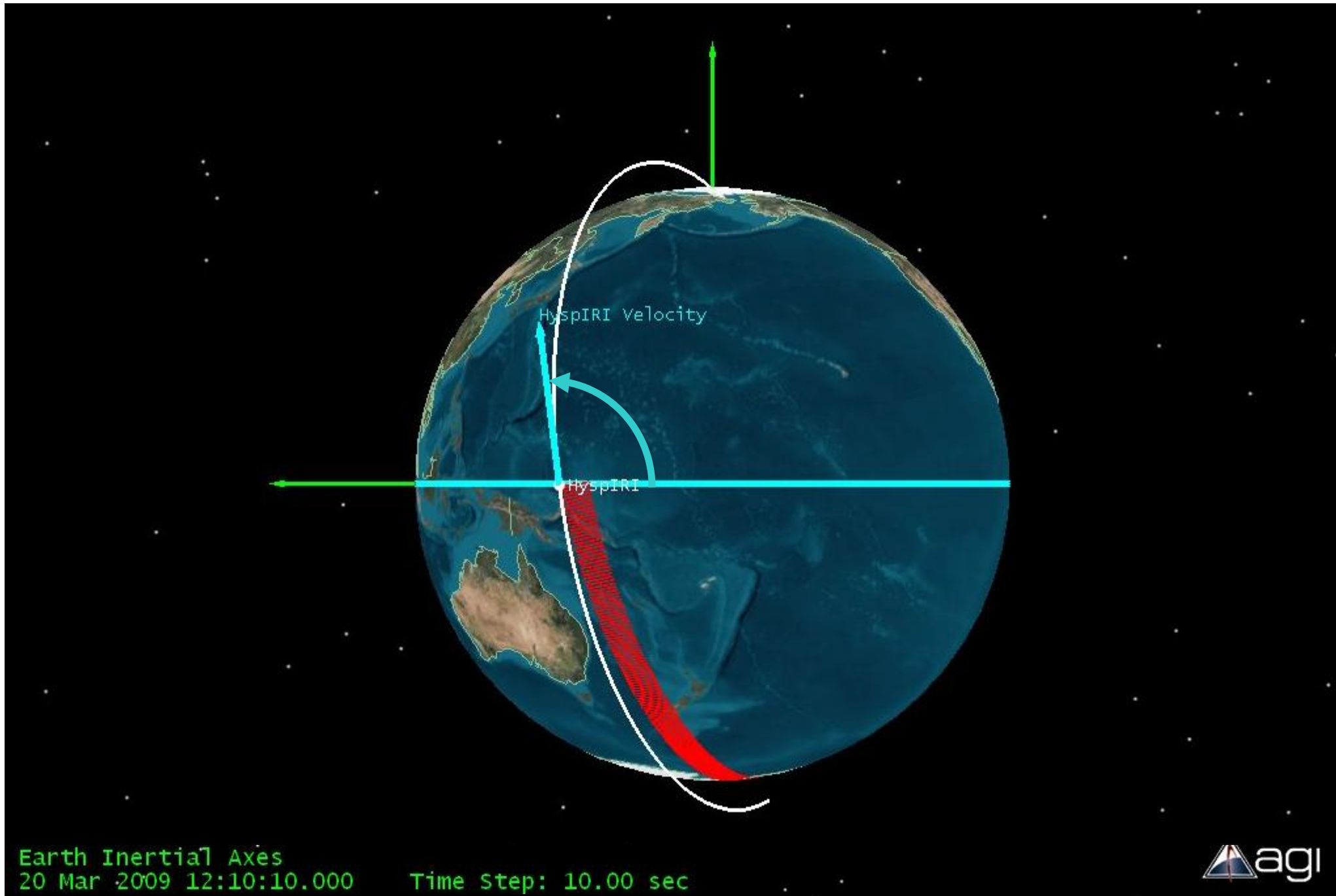
Examples: ICESat, perpendicular orbit planes selected for CLARREO, most EOS platforms

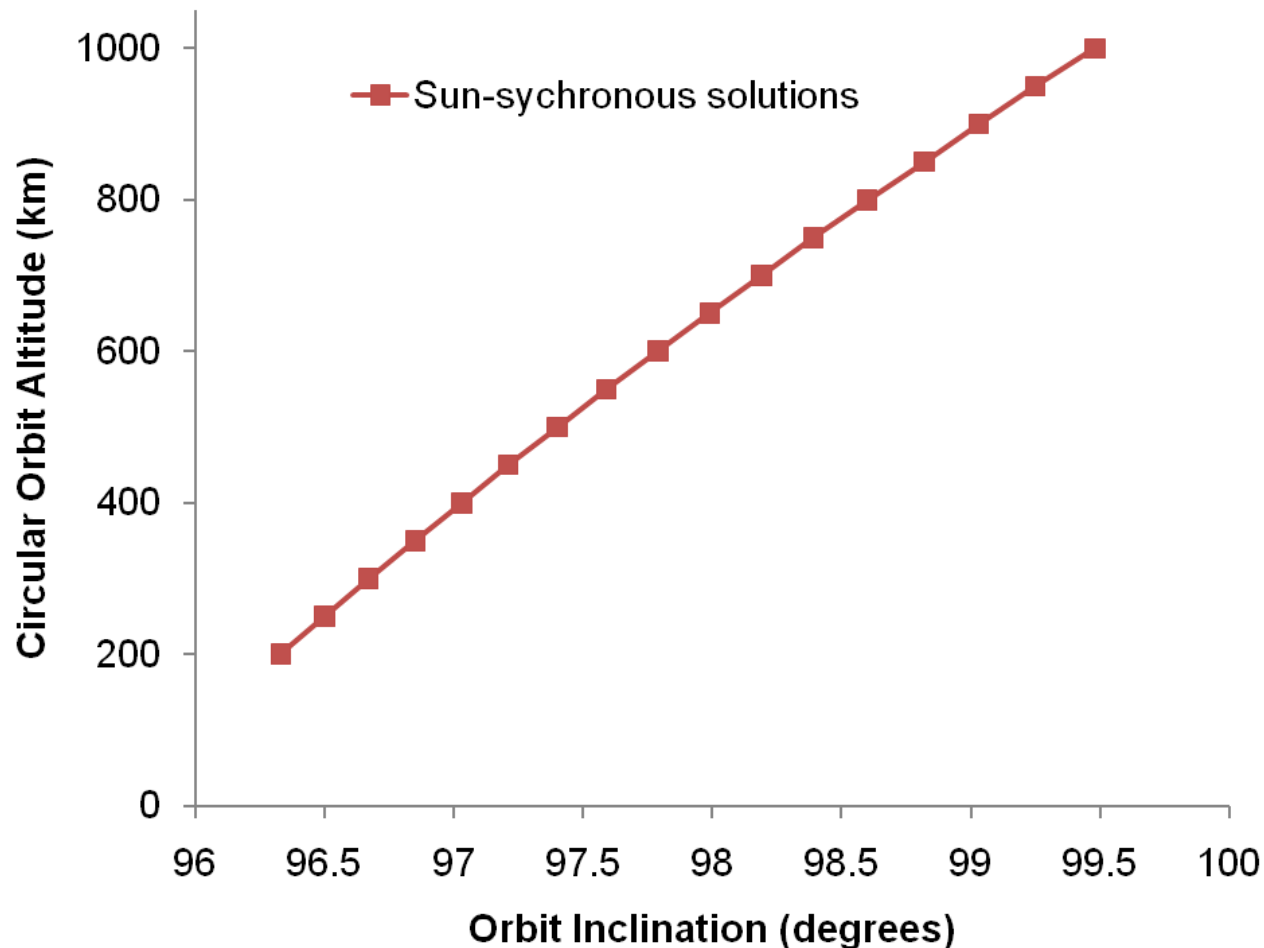
- *Retrograde Orbit*: Orbit moves westward, against the direction of Earth surface's rotation.

Special variant: *Sun-synchronous*—orbit rotates to maintain approx. constant orientation with respect to Sun. The oblate spheroid shape of the Earth accelerates satellites approaching the equator and decelerates them approaching the poles. For near-polar, retrograde orbits < 5000 km altitude, there are orbital inclinations where the nodal precession approximates the apparent mean motion of the Sun.

Examples: Landsat series, Terra, Aqua, EO-1, POES series, most Earth resources satellites

Orbital inclination (97.9 °) represents the angle between the Earth's equatorial plane, and the orbit plane, measured (by convention) at an ascending node.





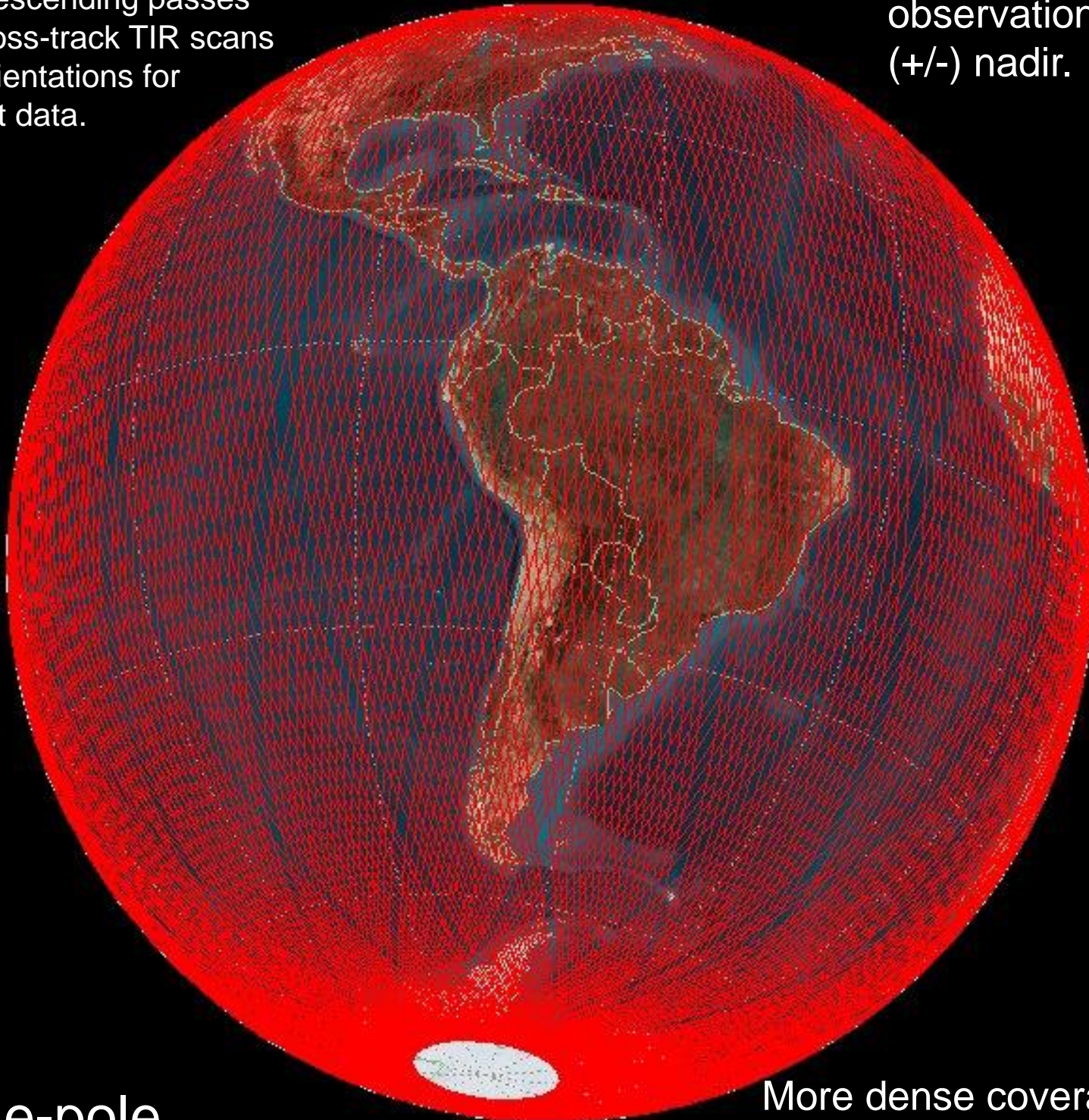
Sun-Synchronous Orbits

For Sun-synchronous orbits the node precession rate is 0.986 degrees/day, to match the average apparent motion of the Sun. Useful LEO solutions are near-polar, retrograde orbits with orbit poles at least 4 deg. latitude away from the Earth's N and S poles.

(Data points from Wertz & Larson, eds. 1999. *Space Mission Analysis and Design*.)

Ascending and descending passes intersect, thus cross-track TIR scans are in different orientations for daytime and night data.

Sun-synch. LEO with observations about (+/-) nadir.

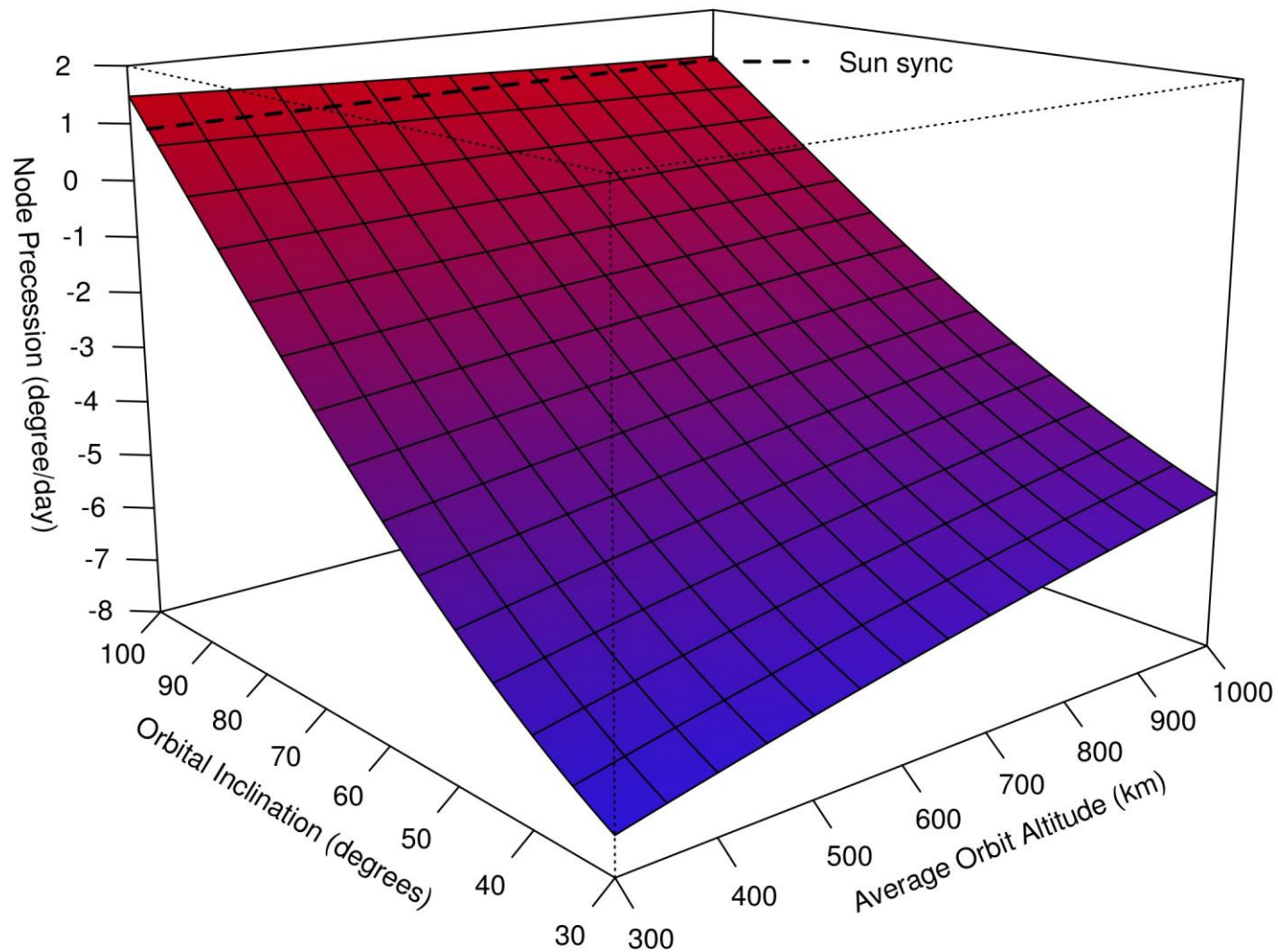


Sun
TIR

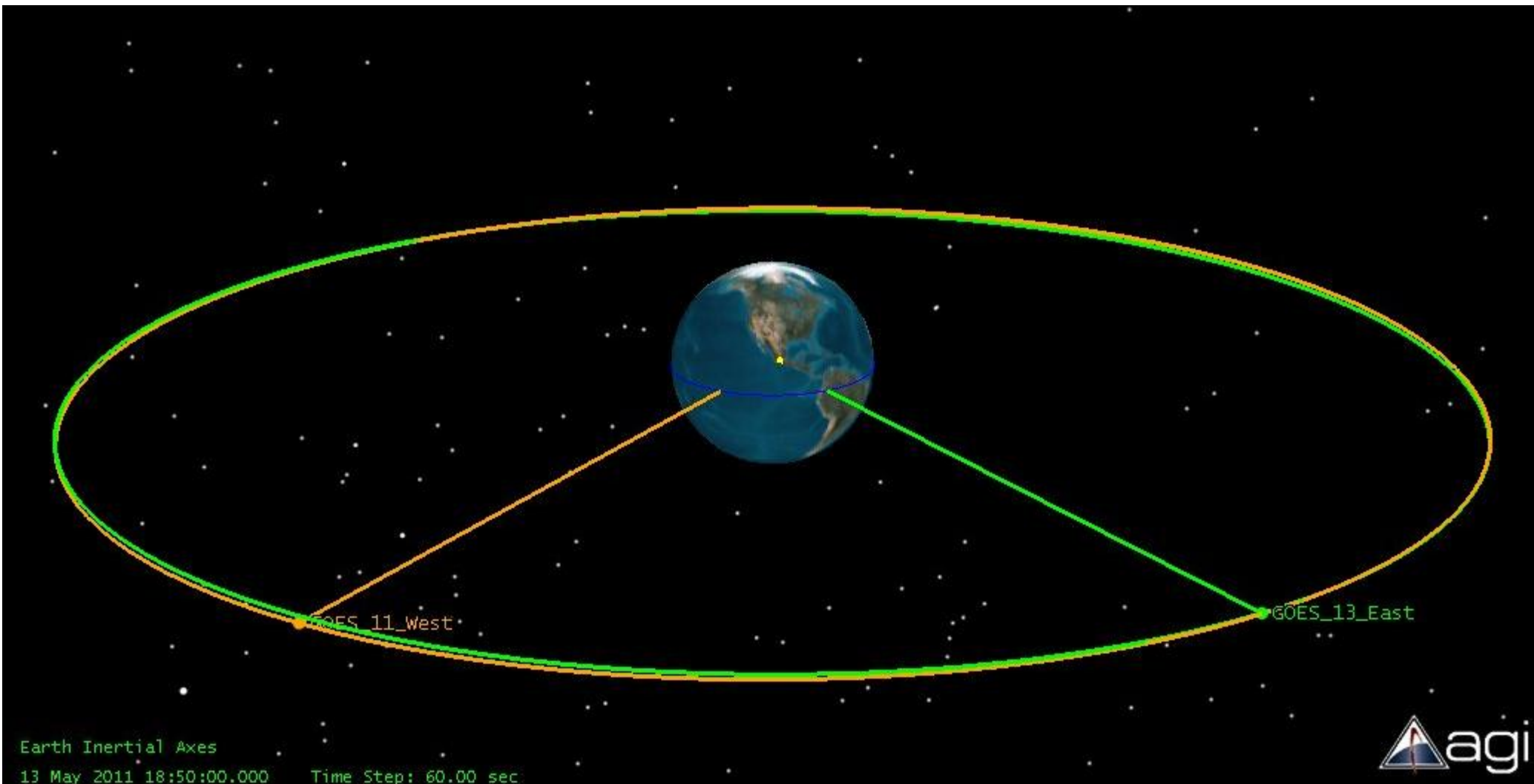
Hole-at-the-pole

More dense coverage near the N & S latitude limits.

**Approximate node precession rates in LEO:
circular orbits with a range of orbit altitudes & inclinations**



GEO Platforms: Continuous (or no) access, with wide range of fixed view geometries; all possible solar illumination geometries



A single GEO platform (e.g., GEO-CAPE) provides a static pattern of viewing angles but can sample the full range of solar illuminations. Contrast this with the restricted illumination geometries from sun-synch. orbits.

Some observations & conclusions

- Sun-synchronous low Earth orbits provide denser coverage near the poles, which may partially offset seasons with low reflected solar radiation.
- The interval between day-night TIR emissive observations decreases near the poles.
- The local apparent time for overpasses is commonly **not** 10:30 AM.
- A mission concept to meet 5-day and < 20 day sampling requirements (the reference orbit and instrument concepts) also provides more highly sampled areas: e.g., high latitudes, overlapping swaths. *(Longitudes with more frequent overlap might shift over the mission life—depending on specs. for maintaining orbit repeat tracks.)*
- TIR data might be used to interpolate ecosystem functional properties (e.g., seasonal canopy leaf phenology) at resolutions coarser than 60 m.
- An orbit designed for repeated global coverage compromises other attributes (e.g., continuous coverage, frequent opportunities for sensor inter-calibration).

